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## WAVELENGTH EXERCISER

### Related Patent Applications

10 U.S. Patent Application "Architecture For A Photonic Transport Network",  
Roorda et al., SN. 09/946,576, filed June 7, 2001 and assigned to Innovance  
Networks, docket 1001.

### Field of the Invention

15 The invention resides in the field of optical WDM networks, and is  
directed in particular to a wavelength exerciser.

### Background of the Invention

20 In agile photonic networks, each signal travels between a different source  
and destination node without unnecessary OEO conversions at all intermediate  
nodes. In other words, the conventional pt-pt based channel boundaries are  
replaced by individual wavelengths (channels) going on-ramp and off-ramp at  
arbitrary network nodes.

25 Fault detection mechanisms which operate traditionally in the electrical  
domain cannot be applied in optical domain. Also, traditional network  
engineering methods cannot be used on end-to-end connections that pass  
through many nodes without OEO conversion, since the connections sharing a  
given fiber link now have substantially different noise and distortion impairments,  
determined by their network traversing history.

30 On the other hand, the agile architecture creates the opportunity to  
replace the existent fault detection mechanisms and the current methods of  
engineering connections with new link engineering methods.

## Summary of the Invention

It is an object of the invention to provide a fault detection mechanism for a flexibility point of an agile network.

It is another object of the invention to provide a method of measuring the  
5 current link/path performance parameters, for speeding-up the path selection process and increasing the chances of establishing a connection along the selected path.

According to an aspect of the invention, a method for evaluating  
connections in an agile network is provided, comprising: (a) for a switching node  
10 of the agile network, selecting a plurality of paths available between the switching node and all remaining nodes of the agile network; (b) for an available path, selecting a plurality of adequate wavelengths according to a wavelength performance parameter; (c) for each adequate wavelength, establishing the test connection along the path; and (d) at preset intervals, repeating step (c) for all  
15 adequate wavelengths, repeating steps (b) and (c) for all available paths, and repeating steps (a), (b) and (c) for all nodes of the agile network.

A network and element management system for a wavelength switched optical network is also provided. The network and element management system comprises at a switching node, a wavelength exerciser for detecting a test path  
20 between the switching node and another switching node; and a call management module for setting up a connection along the test path.

According to a further aspect the wavelength exerciser according to the invention comprises a path selector for selecting a test path between a source node and a destination node; a wavelength assignment module for assigning  
25 successively a plurality of wavelengths to the test path for establishing a test connection along the test path; a fault finder for detecting a fault whenever the test connection fails; and a test connection controller for controlling operation of the path selector, the wavelength assignment module and the fault finder.

Advantageously, the wavelength exerciser according to the invention  
30 provides a solution for detecting faults in the switch and access architectures before the network attempts to establish a connection along the faulted route.

The wavelength exerciser may be used off line to detect faults in the switch during SLAT (system line-up and test) or can be used on-line to verify the paths that are not currently used for live connections.

Also, the wavelength exerciser can be used for collecting on-line measurements of link parameters. This measured performance data may be used for enhanced link engineering, and also for speeding-up the operation of the routing and switching in agile networks.

### Brief Description of the Drawings

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of the preferred embodiments, as illustrated in the appended drawings, where:

**Figure 1** shows an example of an agile system;

**Figure 2** shows an example of the units of a network and element management system involved in wavelength-connection mapping; and

**Figure 3** is a flowchart showing the operation of the wavelength exerciser.

### Detailed Description of the Preferred Embodiments

Figure 1 shows an example of a transparent/agile (wavelength switched) network **100** as described in the above patent application docket #1001. Network **100** includes a plurality of flexibility points (nodes) **A, B, C, Z, X, Y** equipped with wavelength switches, which can switch a channel in optical format, or with optical add/drop multiplexing OADM modules. Each node also comprises a pool of transponders (a long-reach **Rx-Tx** pair and a short reach **Rx-Tx** pair) for local traffic ramp-on/off, and a pool of regenerators/ wavelength converters (a long reach **Rx-Tx** pair) for regenerating and/or converting the wavelength of some channels, based on their performance and network loading.

Network **100** is also provided with optical line amplification units **6, 7**, for conditioning the WDM signal traveling along the respective link for ULR (ultra long reach) transmission. The line amplification units **6, 7**, as well as the pre-amplifier units provided at the switching nodes, include optical amplifiers, which

are preferably equipped with dynamic gain equalization means and dispersion compensation means. Dynamic gain equalizers ensure that an optimal power profile is maintained along the line. Dispersion compensation modules provide advanced fiber-based slope-matched dispersion compensation. Adjustable  
5 (tunable) can also be used in some instances, preferably at the switching nodes.

A plurality of multiple-port optical spectrum analyzers connected throughout network **100**, provides visibility of signal power levels and noise levels.

Based on network topology information, resources availability and  
10 resources operational parameters, a network and element management system NEMS **12** monitors and controls operation of the network nodes and their connectivity, and provides node and network inventory data and various metrics. A signalling and control system SCS **11** is provided between all nodes and links of network **100** to allow topology discovery, fault monitoring, and photonic layer  
15 network management. SCS **11** also enables transferring of device specified and measured data from the respective device to various modules of the NEMS **12**, and provides the devices with target operational parameters.

Figure 1 shows an example of an agile network; the present invention applies to other agile network configurations. A connection **A-Z** is also shown by  
20 way of example.

The term 'connection' refers to transfer of traffic between nodes **A** and **Z**. The term 'path' refers to the route that carries the connection. For example, connection **A-Z** is established in Figure 1 along a path **16** that originates at node **A**, passes through switching nodes **B**, **C** and arrives at the destination node **Z** in  
25 optical format. It is to be noted that connection **A-Z** can also be established along paths **A-X-C-Z**, or **A-B-X-Y-Z**, etc. In any event, network and element management system NEMS **12** selects the best path for the respective connection based on the current network topology, connectivity and loading.

The term 'link' refers to the fiber and equipment between two flexibility  
30 sites, such as shown at **14** in Figure 1.

Figure 2 illustrates a logical overview of the modules of the NEMS **12** which are involved in path selection and the operation of the wavelength exerciser **40** according to the invention.

For establishing a connection in network **100**, the network and element controller **12** is provided with a call management block **21**, which provides a routing and switching management **10** with a connection request. A request specifies the source node and the sink node (e.g. **A** and **Z**), imposes some constraints to the connection, and defines certain conditions according to the class of services applicable to the respective user. Unit **10** comprises a routing module that selects a plurality of best paths that satisfy the connection request, and a regenerator placement module, that places regenerators along these paths whenever needed. A wavelength assignment module of routing and switching management **10** assigns wavelengths to all regenerator segments.

RSM **10** also orders the path list according to their chances of success and maintains this list until a path is successfully setup. It presents the paths from the list one by one to the call management **21**, which in turn attempts to set-up a path. If the first path on the list fails, the call management **21** requests the next path from the list, and so on, until the connection is setup.

The RSM **10** operates based on regenerator placement rules and constraints and on wavelength placement rules. The paths are selected based preferably on their cost and performance. To this end, the RMS **10** invokes a Q calculator **39** for calculating the Q for each regenerator segment, and for the entire path.

The wavelengths are also selected by RSM **10** according to their performance for the type of fiber used on the respective link, the launch power for the respective wavelength, etc, which information is available in database **20**.

To enable full connectivity in network **100**, NEMS **12** is provided with a topology database (data topology system DTS) **15** connected to all nodes of network **100** over signaling and control system SCS **11**, as shown by interface **13**. DTS **15** comprises updated information on network configuration and also comprises links to the specifications of the optical devices of network **100**. The

network configuration information includes, but is not limited to, network inventory information, connectivity information, information on current link loading, channel availability, etc. Device specifications (which may also include fiber specifications), include the operational parameters of the respective device as provided by the manufacturer and stored at the respective device.

Figure 2 also shows a measurement database **27** which stores performance data measured at various points in network **100** and supplied over the signaling and control system **11**, as shown by interface **28**. The measured performance data includes measurements that are obtained from various network devices. For example, a transmitter **Tx** can provide the effective launch power for the respective wavelength. A receiver **Rx** can provide eye closure and BER information. Also, the receivers can measure dispersion of the respective regenerator section. The optical amplifiers **OA** may provide span gain/loss information, reflection measurements, noise figure, power levels, etc.

Measured performance data are also collected in various points of network **100** using optical spectrum analyzers **OSA** provided at switching nodes and amplifier sites. The OSA monitoring runs continuously to provide visibility of signal power levels and noise levels in the respective points.

Database **27** is generically illustrated as a centralized entity; however some of measured performance data can be stored at the respective device and the database **27** may provide a link to the respective information. As well, the measured performance data may be stored in DTS **15**.

The Q calculator **39** is capable of extracting data for one or more channels, and calculating eye closure, nonlinear Q, WDM Q, OSNR Q and total Q. Much flexibility is offered regarding the complexity of processing, the way parameters are specified, or the type of graphical output that is generated. Once Q is below a threshold, signal regeneration is provided in the respective path, or the respective path is abandoned in favor of a new path that operates according to the user specification(s).

The wavelength exerciser (WE) **40** operates at each node of network **100** as described in connection with Figures 2 and 3. The exerciser can operate on-

line, in which case it establishes test connections on un-used wavelengths, operating at scheduled intervals as a background task. As well, the exerciser can be used as part of SLAT (system line-up and test) to set-up all the connections in the network for network commissioning test. In both modes of operation, the exerciser can assume a plurality of roles in a network, such as:

1) To set-up test connections from each node to all other nodes of the network. In this role, the wavelength exerciser can detect faults in the switch and access architecture.

2) To collect performance data about all links of the network. In traditional networks, span engineering can be performed only during SLAT, at which stage measured data are not available. Experimental evidence shows that use of measured as opposed to estimated data might increase the network deployed reach by 50%. Thus, the measured performance data can be used to:

- accurately calibrate the Q calculator **39**. When path selection is based on the Q factor calculated using measured link/path data rather than estimated data, the chances of successfully setting-up a selected path increase significantly.

- select the fixed dispersion compensating modules provided throughout the network. This provides a better control of the link dispersion, and ultimately a better quality signal at the receiver.

- adjust the tuneable components of the network. In this way, additional optimization may be performed on each individual connection by adjusting the operational parameters of the respective path.

- characterize the link gain/loss. This allows adjustment of the launch power and of the dynamic gain equalizers provided throughout the network. This also allows the link control to perform advanced power management by providing the gain and power targets for the control loops.

As seen in Figure 2, the wavelength exerciser **40** comprises a path selector **24** and a wavelength assignment module **25** which operate under control of a test connection controller **22**. The path selector **24** identifies all paths originating on a node, as shown by steps **30** and **31** in Figure 3, and also

identifies all idle transponders at that node and all wavelengths that are free at the respective time, step **32**. This information is available from the topology database **15**. A free wavelength is a wavelength that is not used for carrying live traffic at the time of testing, and an idle transponder is a transmitter-receiver pair, which is not generating or detecting optical signals at the time of testing.

The call manager **31** is then invoked to set-up connections on each link, step **33**, using the wavelengths that are free on that link. This is performed as a background task in step **34**.

The WE **40** also takes into account the wavelength performance for the respective link, available from wavelength performance database **20**, so that only the wavelengths that have chances of establishing a connection are exercised. For example, if database **20** indicates that reach of wavelength  $\lambda_1$  is under 1,000 Km, and the link/path under control is longer than that, wavelengths  $\lambda_1$  would not be tested on this particular link/path.

If the call manager **21** cannot setup a certain wavelength on the respective link, a fault is signaled, as shown on the YES branch of decision block **35**. The wavelength exerciser is provided with a fault finder **23**, which can give a good indication of the location of the fault.

Thus, if the test connection is to be established between two consecutive nodes, the exerciser will verify the access structure. In this case, the route for the respective test connection passes at the source node from the transmitter through the add structure to the postamplifier, then over the fiber link including the optical amplifiers to the destination node. At the destination node, the route will pass through the preamplifier and the drop structure to the respective receiver. Since each wavelength may be directed in the drop structure along a different route depending on which receiver is allocated to the connection and the wavelength used for the test connection, WE **40** will test for continuity and connectivity along different branches of the drop structure.

If the connection is established over a passthrough node, the exerciser can verify the architecture of the passthrough switch. The connection can be transferred from the same input port of the switch to a plurality of output ports in



turn, depending on the wavelength used for the respective connection, to verify the continuity of the internal switch routes. Again, when the testing is performed on-line, only the switch internal routes not used by live connections are verified at the time of testing.

5           It is to be noted that in an agile network **100** the connectivity map of the switches/network changes in time, due to the dynamic set-up and removal of connections based on the current user requests. In this way, all paths have a chance to be tested under various network loading conditions after a certain time.

10           WE **40** may also drive in-service measurements of a variety of parameters, step **36**, such as dispersion, gain/loss, input and output power, reflection information. Other parameters may also be measured, if necessary. The Q calculator **39** then determines the Q factor for each link and other associated parameters, shown at step **37**. The results can be recorded in  
15           measurement database **27**.

          Routing management **10** may use the link performance data collected by the wavelength exerciser subsequently for path selection. Since the path performance is in this case calculated based on current, measured parameters, the path-set-up time is significantly reduced, while the chances of successfully  
20           setting the connection along the respective selected path increase significantly.

          The wavelength paths that are set-up by the exerciser can additionally be used to optimize parameters that require long path measurements.

          For example, WE **40** can be used to characterize the chromatic dispersion CD of the link in the unused channel slots. This allows for better understanding  
25           of the CD of the system, which in turn allows for a more accurate selection of the fixed dispersion compensating modules provided in the transmission line at the optical amplifier sites. More importantly, the WE **40** provides feedback for any tunable dispersion compensation placed in the pre-amplifiers at the flexibility sites.

30           WE **40** can also be used to characterize the link gain/loss. This information can be used for optimizing parameters such as launch power into the

fiber, wavelength tolerance/tuning, etc. Also, WE 40 can be used to set-up the best value for the dynamic gain equalizers (DGE) provided along the link at the amplifier sites. By setting-up the attenuation of the DGE, the best set-point for a new live channel is determined faster after the channel is added. The DGE value

5 can be determined using alternative techniques; however use of the WE 40 provides the most accurate view of the required attenuation setting.